Original Article

Morphometric Analysis of Facet and Lamina Resection in Minimally Invasive Posterior Cervical Laminoforaminotomy and Its Clinical Outcomes

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Abstract

Background: Minimally invasive posterior cervical foraminotomy (MI-PCF) is used to treat cervical radiculopathy, but quantitative limits of bony decompression that preserve stability are not well defined. The objective is to evaluate surgical and clinical outcomes of MI-PCF and to describe morphometric ranges of facet and lamina resection associated with favourable results and preserved stability. **Material and Methods:** A cadaveric morphometric study of five specimens (C3–C7, bilateral) was conducted to determine the optimal bony resection required for adequate exposure, defined as 7 mm of the superior facet, 5 mm of the inferior facet, and 5 mm of lamina drilling. Based on these parameters, a prospective series of 34 patients with unilateral cervical radiculopathy underwent MI-PCF at the sub-axial cervical spine. Radicular pain was assessed using the visual analogue scale (VAS), and functional status was graded with modified Odom's criteria. Postoperative safety was evaluated for cervical instability and complications, with clinical and radiological follow-up. Intraoperative measurements of facet and lamina removal were expressed as percentages of the original bony dimensions and grouped into resection categories. **Results:** Mean age was 50 years. Mean VAS scores improved from 7.4 ± 0.6 preoperatively to 1.5 ± 0.4 postoperatively ($p < 0.05$). Good–excellent outcomes were achieved in 97% of patients; one patient had transient motor weakness that resolved by six months. No cervical instability, dural tears, or wound infections occurred. Overall, mean facet and lamina resections were 33.2% and 31.5%, respectively, with most procedures clustered between 30–35% resection and fewer than 10% of segments exceeding 40%. **Conclusion:** MI-PCF provided pain relief, excellent functional recovery, and a low complication rate while maintaining cervical stability. Cadaveric morphometric guidance offers a reproducible and anatomically safe corridor for adequate Decompression was achieved when facet and lamina resections were confined to a one-third window of their dimensions.

Keywords: cervical radiculopathy, minimally invasive posterior cervical foraminotomy, facet resection, lamina resection, morphometric analysis, spinal stability.

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Introduction

Cervical radiculopathy is a frequent cause of neck and arm pain in working-age adults, with substantial impact on productivity, sleep, and quality of life. Many of these patients eventually fail conservative therapy and require surgical decompression of the affected nerve root. Anterior cervical discectomy and fusion (ACDF) have long been regarded as the standard procedure. Still, it sacrifices motion at the index level and may predispose to adjacent segment degeneration and implant-related complications.[1-3] Unlike anterior fusion procedures, posterior cervical foraminotomy provides a more direct route to the compressed nerve root. When performed using a minimally invasive technique, it allows targeted foraminal decompression while maintaining the native motion segment. In addition, it helps preserve the paraspinal musculature and largely respects the spine's normal biomechanics.[4,5]

In an ideal scenario, posterior decompression would reliably relieve radicular pain, maintain or restore function, and do so without compromising segmental stability. The key technical challenge lies in how much of the facet and lamina can be safely removed to achieve adequate neural decompression without destabilising the motion segment. Biomechanical and cadaveric studies suggest that resection of more than half of the facet joint substantially increases segmental motion and torsional flexibility, while more limited resections appear better tolerated.[6,7] At the same time, cadaveric anatomic work has

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shown that adequate exposure of the foraminal nerve root can often be obtained with the removal of roughly one quarter to one third of the lateral mass or facet complex.[8,9] Translating these experimental "rules of thumb" into reproducible intraoperative practice, however, remains difficult. Previous clinical series of minimally invasive posterior cervical foraminotomy (MI-PCF) have focused primarily on pain relief, functional scores, and complication rates, and they generally report high rates of symptomatic improvement and low Perioperative morbidity.[4,5,10,11,13] Yet, most of these reports describe the decompression qualitatively ("keyhole," "undercutting," "partial facetectomy") rather than quantifying resection in morphometric terms. Conversely, morphometric studies of cervical facets, lateral masses, and neural arches, whether on dry bones or imaging datasets, provide detailed measurements but are rarely linked to real-world surgical resections and clinical outcomes.[9–11,25,29] As a result, surgeons still rely heavily on experience and visual impression when judging how much bone to remove during MI-PCF. This disconnect has clear clinical consequences. When too much facet is removed, segmental stability can be compromised. This may increase the risk of postoperative kyphosis, recurrent radiculopathy, or the later need for fusion surgery.[5,6,17,23] If too little bone is taken, the opposite problem arises. Residual foraminal stenosis may persist, arm pain may continue, and the primary purpose of decompression is not achieved. Finite-element studies and contemporary minimally invasive series repeatedly emphasise this narrow margin between adequate decompression and preserved stability.[11,12,14,18] However, they rarely translate this balance into a simple, percentage-based "safe window" that is explicitly linked to clinical outcomes. The present study was designed to address this gap. A prospective clinical series of MI-PCF was coupled with a cadaveric morphometric analysis to test the proportional ranges of facet and lamina resection that still yield good outcomes and maintain stability. The underlying idea is straightforward. Decompression and stability lie on a continuum, and a data-driven morphometric window may provide a practical reference for intraoperative decision-making.

Objectives

The study had two primary objectives.

To quantify the percentage of facet and lamina resection at the operated levels and to validate these morphometric ranges, a cadaveric model was used. The aim was to define a reproducible "safe corridor" for MI-PCF that can guide routine practice.

To evaluate the surgical and clinical outcomes of minimally invasive posterior cervical laminoforaminotomy in patients with unilateral cervical radiculopathy.

Outcomes were assessed using visual analogue scale pain scores, modified Odom's criteria, and complication rates.

Materials and Methods

Study Setting and Design

This study was designed as a prospective clinical cohort analysis with an embedded cadaveric morphometric substudy. All clinical procedures were performed at a high-volume tertiary care neurosurgical center of MS Ramaiah Medical College, Bangalore, Karnataka, India, between January 2020 and December 2023. This observational design was chosen because the primary aim was to evaluate real-world surgical and clinical outcomes of minimally invasive posterior cervical laminoforaminotomy (MI-PCF) and to link these outcomes to the actual extent of bony decompression.

Patient Selection and Eligibility Criteria

The clinical cohort consisted of consecutive adult patients presenting with unilateral cervical radiculopathy that was refractory to at least 6 weeks of structured conservative treatment. Eligible patients were aged 18 to 70 years, had radicular pain corresponding to a single cervical root, and demonstrated concordant foraminal stenosis or lateral disc, far lateral disc herniation at subaxial spine on magnetic resonance imaging, with or without corroborative computed tomography. Patients with central and paracentral disc, with signs of cervical myelopathy, multilevel disease requiring fusion, prior cervical spine surgery, trauma, infection, tumour, or preoperative evidence of segmental instability on dynamic radiographs were excluded. These criteria were intended to create a relatively homogeneous cohort in which MI-PCF is an accepted motion-preserving alternative to anterior fusion procedures.

Preoperative Clinical Assessment and Conservative Management

Preoperative evaluation followed a standardised protocol. All patients underwent detailed clinical assessment, including neurological examination, documentation of dermatomal pain distribution, and grading of motor and sensory deficits where present. Pain intensity was quantified using a 10-point visual analogue scale (VAS) for radicular pain. Baseline functional status was recorded and later graded with modified Odom's criteria at follow-up, in line with contemporary trials of posterior Cervical foraminotomy.[1,3] Conservative management, before inclusion in the surgical cohort, comprised appropriate analgesia, neuropathic agents where indicated, short courses of cervical immobilisation, and supervised physiotherapy focused on posture and neural mobilisation [Figure 1].

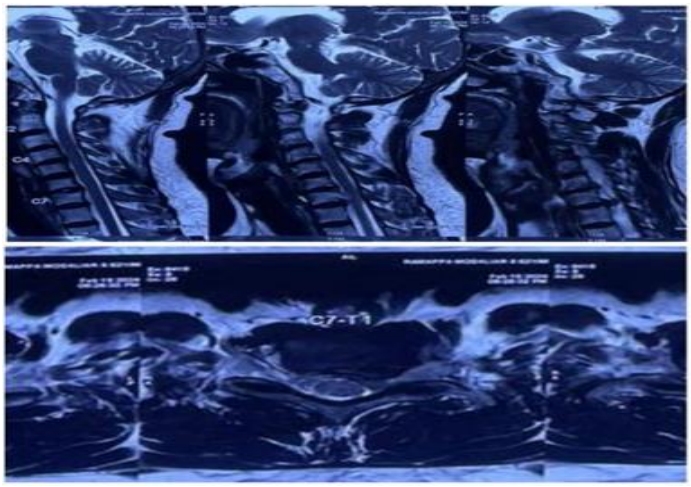

Figure 1: MRI Sag and Axial- suggested C6-7 lateral disc

Cadaveric Morphometric Study: A total of five embalmed cadaveric specimens were used to assess the extent of bony resection required for adequate exposure of the cervical intervertebral foramen. Bilateral laminoforaminotomies were performed from C3 to C7 using standard microsurgical techniques. Measurements were recorded using a digital Vernier caliper at three critical points: -Superior facet resection: 7 mm, Inferior facet resection: 5 mm, Lamina drilling: 5 mm [Figure 2].

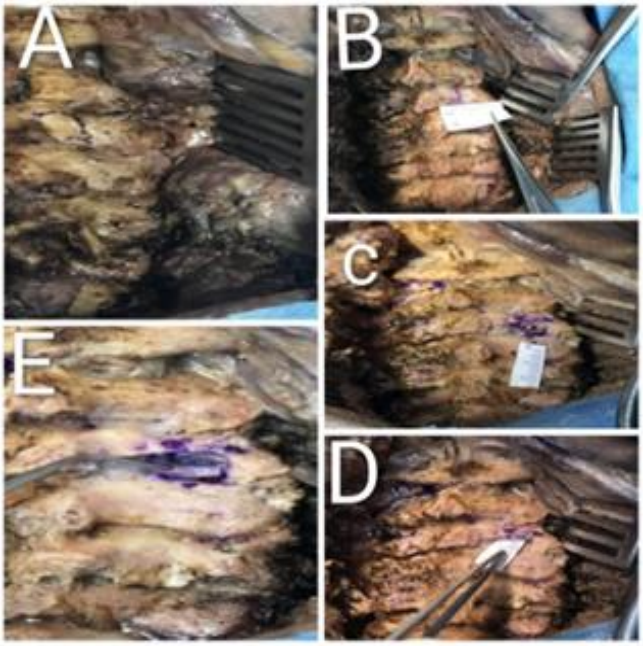

Figure 2: A- exposed lamina and faces, B- 5 mm of lamina, C- 5 mm of inferior facet, D- 7 mm of superior facet, E-Adequate exposure after drilling.

Surgical Technique for Minimally Invasive Posterior Cervical Foraminotomy: All operations were performed under general anaesthesia using a standardised MI-PCF technique by two fellowship-trained spine surgeons with experience in minimally invasive posterior cervical procedures. Patients were positioned prone, with the cervical spine maintained in neutral to slight flexion. The target level was localised with fluoroscopy, 0.5 mm from midline, and a 16 to 18-mm paramedian skin incision was made on the symptomatic side. Sequential dilators were inserted to dock on the lamina–facet junction, and a tubular retractor was then fixed to the table-mounted arm. Under operating microscope magnification, using a high-speed drill and a Kerrison punch, according to the measurements from the cadaveric study, 5 mm of the inferior facet, 7 mm of the superior aspect, and 5 mm of the lamina were drilled, and the ligamentum flavum was exposed. The ligamentum flavum was resected as needed to visualise the traversing and exiting nerve root. The annulus was cut, or the extruded disc fragment was removed. Foraminal decompression continued laterally until the affected root was freely mobile and visibly decompressed. Haemostasis was secured, the tubular retractor was removed, and the wound was closed in layers without drains [Figure 3 -6].

Figure 3: X ray after docking at the level.

Figure 4: After drilling exposure of disc Fragment with nerve root.

Figure 5: Evacuation of disc fragment.

Figure 6: Free nerve root after discectom

Radiological Morphometric Assessment in the Clinical Cohort: Morphometric assessment of bony resection in the clinical cohort relied on a combination of intraoperative landmarks and postoperative imaging. Facet and lamina dimensions at the operated level were measured on preoperative and postoperative computed tomography using the institution's picture archiving and communication system. The mediolateral width of the facet was defined from the medial border at the lamina–facet junction to the lateral edge of the articular surface. Lamina height was measured from the base of the spinous process to the inferomedial edge of the facet. The length of bone removed during laminoforaminotomy was measured on postoperative images along the same axes, and the percentage of resection was calculated using the formula: percentage resection = (resected length / original length) × 100. All measurements were performed independently by two blinded observers, with discrepancies resolved by consensus. This approach was aligned with earlier anatomical work that quantified lateral mass and lamina anatomy to guide posterior cervical foraminotomy.[4,5]

Cadaveric Morphometric Substudy and Validation of Resection Range

In parallel, a cadaveric morphometric substudy was conducted in the institutional anatomy laboratory to validate the proportional ranges of facet and lamina removal observed clinically, which was based on the Morphometric Analysis for Surgical Treatment of Cervical Discopathy by Posterior Laminoforaminotomy: Radiologic Study and Technical Note by Tomasz A. Dziedzic et al. Ten formalin-fixed cervical spine specimens from C2 to T1 were mounted in a prone position. Pre-procedure measurements of facet width and lamina height were obtained with digital calipers. The markings of 5mm of the inferior facet, 7 mm of the superior aspect, and 5 mm of the lamina were marked with the scale and drilled (7-5-5 corridor). After completing the simulated laminoforaminotomy, the residual facet and lamina were re-measured Directly on the specimens. This was then compared with a planned target of about one-third resection, based on earlier biomechanical work suggesting that half of the facet joint should be retained to maintain stability, and that this amount of drilling is adequate for exposure and to avoid instability.[6,7]

Postoperative Follow-up, Outcome Measures, and Assessment of Stability. Patients were reviewed in the outpatient clinic at 6 weeks, 3 months, 6 months, and 12 months after surgery, with extra visits arranged if needed. At each visit, arm pain was scored on a 10-point visual analogue scale, and overall clinical outcome was graded using the modified Odom's criteria. Any new or persistent neurological deficit was carefully documented.

Stability of the operated segment was checked on imaging. Lateral flexion–extension radiographs were obtained at 6 and 12 months, and instability was defined as more than 3 mm of sagittal translation or more than 11° of angulation at the operated level. When clinically indicated, postoperative CT scans were examined for facet collapse, progressive kyphosis, or recurrent foraminal narrowing. All complications, including wound infection, dural tear, cerebrospinal fluid leak, reoperation, and readmission, were recorded prospectively.

Statistical Analysis: Statistical analysis was mainly descriptive, in keeping with the exploratory design of this study. Continuous variables, including age, VAS scores, and the percentage of bone resection, were summarised as mean ± standard deviation. When the data were not normally distributed, they were presented as median values with their ranges. Categorical variables, including Odom outcome categories and complication rates, were summarised as frequencies and percentages. Preoperative and postoperative VAS scores were compared using a paired Student's t test after confirming approximate normality of differences. A p-value less than 0.05 was considered statistically significant. Morphometric variables were summarised by operated level and by percentage categories of facet and lamina resection. Given the modest sample size, analyses relating resection categories to clinical outcomes were restricted to exploratory cross-tabulations without formal multivariable modelling. All Analyses were conducted using standard statistical software packages available at the institution.

Ethical Considerations: Ethical approval for the clinical and cadaveric components was obtained from the Institutional Ethics Committee of the MS Ramaiah Medical College, Bangalore, Karnataka, India, before the initiation of the study, and all procedures adhered to the principles of the Declaration of Helsinki. Written informed consent was obtained from all patients after explaining the nature of MI-PCF, alternative surgical options, and the additional imaging required for morphometric analysis. Cadaveric specimens were handled in accordance with institutional policies for anatomical research and teaching.

Results

A total of 34 patients underwent minimally invasive posterior cervical laminoforaminotomy (MI-PCF) during the study period. The cohort included 16 males (47%) and 18 females (53%), with a mean age of 50 years (range 25–65 years), as detailed in [Table 1].

Table 1: Demographic Profile of Patients Undergoing MI-PCF (N = 34)

Variable	Category	n	Percentage (%)
Sex	Male	16	47
	Female	18	53
Age (years)	Mean	–	50
	Range	–	25–65

The operated segments were distributed across C4–C5 (n = 10), C5–C6 (n = 16), and C6–C7 (n = 8), corresponding to

29.4%, 47.1%, and 23.5% of levels, respectively.

Radicular pain decreased substantially following surgery. The mean preoperative VAS score of 7.4 ± 0.6 fell to 1.5 ± 0.4 in the postoperative period, representing a statistically significant improvement in pain intensity ($p < 0.05$) [Table 2]. This reduction translates into an approximate 6-point change on the VAS, indicating marked relief of radicular symptoms in most patients.

Table 2: Change in Radicular Pain Intensity (VAS Scores) Before and After MI- PCF (N = 34)

Time Point	Mean VAS Score ± SD	p-value vs Preoperative
Preoperative	7.4 ± 0.6	–
Postoperative	1.5 ± 0.4	$p < 0.05$

Functional outcomes assessed using the modified Odom's criteria were predominantly favourable [Table 3]. Good–excellent results were achieved in 33 of 34 patients (97%), while 1 patient (3%) had a fair outcome; no poor results were recorded [Table 3]. The single fair outcome was attributable to postoperative motor weakness, which resolved completely within six months without further surgical intervention.

Table 3. Functional Outcome According to Modified Odom's Criteria (N = 34)

Outcome Category	n	Percentage (%)
Good–excellent	33	97
Fair	1	3
Poor	0	0

Note: The single fair outcome was due to postoperative motor weakness, which resolved completely within six months.

The safety profile of MI-PCF was high in this series [Table 4]. No patient developed clinical or radiological evidence of cervical instability during follow-up. There were no instances of dural tear or wound infection. Apart from the single episode of transient motor weakness (3%), no other significant neurological or wound-related complications were observed [Table 4].

Table 4: Postoperative Safety and Complications After MI-PCF (N = 34)

Parameter	n	Percentage (%)
Cervical instability (clinical/radiological)	0	0
Dural tear	0	0
Wound infection	0	0
Transient motor weakness	1	3

Morphometric analysis of decompression demonstrated that facet and lamina resection could be maintained within a controlled range while still achieving adequate decompression (Table 5). Mean facet resection ranged from 31.2 ± 4.5% at C4–C5 to 35.1 ± 4.7% at C6–C7, with an overall mean of 33.2 ± 5.0% (range 24–43%). Mean Lamina resection varied from 29.8 ± 4.1% at C4–C5 to 33.4 ± 4.3% at C6–C7, yielding an overall mean of 31.5 ± 4.6% (range 22–41%) [Table 5].

Table 5: Morphometric Characteristics of Facet and Lamina Resection at Operated Levels

Operated Level	Operated Segments (n)	Mean Facet Resection (% ± SD)	Facet Resection Range (%)	Mean Lamina Resection (% ± SD)	Lamina Resection Range (%)
C4–C5	10	31.2 ± 4.5	24–39	29.8 ± 4.1	22–37
C5–C6	16	33.6 ± 5.2	25–42	31.7 ± 4.8	24–40
C6–C7	8	35.1 ± 4.7	27–43	33.4 ± 4.3	26–41
Overall	34	33.2 ± 5.0	24–43	31.5 ± 4.6	22–41

When facet resection was stratified into percentage categories, the majority of segments clustered in the 30–35% range (n = 13, 38.2%), followed by <30% and 36–40% categories (each n = 9, 26.5%), while only 3 segments (8.8%) required >40% resection [Table 6].

Table 6: Distribution of Facet Resection Across Percentage Categories (N = 34)

Facet Resection	n	Percentage (%)
< 30%	9	26.5
30–35%	13	38.2
36–40%	9	26.5
> 40%	3	8.8

A similar pattern was observed for lamina resection: 15 segments (44.1%) fell within the 30–35% category, 11 (32.4%) were <30%, 6 (17.6%) were in the 36–40% group, and only 2 (5.9%) exceeded 40% [Table 7].

Taken together, the clinical, safety, and morphometric data [Table 1–7] indicate that MI-PCF provides substantial pain

relief and excellent functional outcomes in most patients, while preserving cervical stability by keeping facet and lamina resection within a relatively narrow, reproducible percentage range.

Table 7: Distribution of Lamina Resection Across Percentage Categories (N = 34)

Lamina Resection Category	n	Percentage (%)
< 30%	11	32.4
30–35%	15	44.1
36–40%	6	17.6
> 40%	2	5.9

Discussion

This study shows that minimally invasive posterior cervical laminoforaminotomy can achieve substantial and reliable symptom relief while maintaining segmental stability when facet and lamina resection are kept within a relatively narrow corridor, as postulated in the 7-5-5 corridor. Radicular pain fell from a mean VAS of 7.4 to 1.5, and 97% of patients achieved good–excellent outcomes on modified Odom's criteria, with no clinical or radiological instability at one year. These figures sit at the upper end of success rates reported for MI-PCF and related posterior approaches, where good–excellent outcomes typically range between 80% and 95% and reoperation or complication rates remain modest.[1-4]

Within the broader motion-preservation paradigm, these findings are consistent with randomized and comparative data indicating that posterior cervical foraminotomy is at least noninferior to ACDF for arm pain relief, with the added advantages of preserving the index-level motion segment and reducing approach-related complications.[5–8] Contemporary series of full-endoscopic and biportal posterior decompression also report high rates of pain-free survival and patient satisfaction, again with very low rates of radiographic instability.[3,4,9] Our cohort aligns with this clinical signal. Still, it adds a quantitative dimension: in all cases, facet and lamina resections clustered around approximately one-third of the original dimension, and instability was not observed even at the upper morphometric margins. From a theoretical standpoint, the results resonate with load-sharing models of the cervical spine and the decompression–stability continuum. Facet joints are estimated to carry roughly 30% of cervical axial load and play a disproportionate role in resisting shear and extension.[10,11] Biomechanical and endoscopic series have long warned that removing more than half of the facet joint accelerates motion and raises the risk of segmental instability, leading to the widely cited "50% rule" as a pragmatic upper limit.[12,13] Finite element work on graded foraminotomies extends this view, suggesting that incremental facet loss produces near-normal kinematics up to a certain threshold. Beyond this range, the motion and disc stresses rise steeply.[14,15] The present study supports this conceptual model. Still, it narrows the clinically relevant band: the 7-5-5 corridor. A 30–35% resection of both facet and lamina appears sufficient for effective foraminal decompression, with no evidence of early instability.

However, the absence of late follow-up beyond one year means that subtle progressive changes in alignment or adjacent segment loading cannot be excluded, and long-term data will be needed before a rigid threshold is adopted.[16-18]

Several limitations temper the strength of these conclusions. The cohort was relatively small, drawn from a single tertiary center, and did not include a parallel ACDF or disc replacement control group, which limits direct comparative inference. A follow-up of 12 months, although adequate to detect early instability, is insufficient to characterise adjacent segment degeneration or late recurrence. Morphometric measurements were derived from a single cadaveric reading, which may not fully capture three-dimensional curvature and facet orientation. Only a small minority of segments exceeded 40% resection, so the upper boundary of the "safe" range remains less certain. Finally, selection bias is possible, since patients with multilevel disease, overt myelopathy, or pre-existing instability were excluded by design.

Future research should build on this morphometric framework in several directions. Multicentre prospective cohorts or randomized trials comparing MI-PCF with ACDF and cervical disc replacement, incorporating standardized measurement of facet and lamina resection, would help determine whether a one-third window generalizes across techniques and patient populations. Patient-specific finite element models could be calibrated with such clinical data to explore how bone quality, disc degeneration, and preoperative alignment interact with graded resection. Intraoperative navigation or augmented reality could be used to provide real-time quantitative feedback on resection percentages, allowing the proposed corridor to be tested and refined in a controlled fashion.

Conclusion

In our series of 34 patients, arm pain improved clearly after surgery. The mean VAS score fell from 7.4 before the operation to 1.5 at follow-up. Most patients did well clinically: 33 of 34 (97%) were graded as having good or excellent outcomes on modified Odom's criteria. There was no radiological evidence of segmental instability on dynamic X-rays. One patient developed new motor weakness after surgery, but this improved completely over the following months.

Morphometric review showed that the 7-5-5 corridor resulted in the removal of adequate amounts of facet and lamina in most cases. This level of resection seemed sufficient to decompress the nerve root while maintaining the motion segment stability. On this basis, a simple "7-5-5 corridor" can be suggested as a practical guide for bone removal in MI-PCF. This provisional range now needs to be tested and refined in larger, multicentre studies with longer follow-up.

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Conflicts of interest
There are no conflicts of interest.

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